

ω V a1, 10
 ω V b1, 5
 ω V a1, 1

10 10
 01 01

20 10
 20 10

10 10
 20 10

ω V a1
 ω V b1
 ω V a1

Ex: number of coil = 48, $P = 4$ poles, Lab winding each coil has 10 turns each turn has a Resistance value with 0.01 Ω , simplex

48 coil - 10 turns/coil - $R_{turn} = 0.01 \Omega$

4 poles

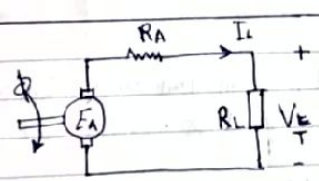
Lab $\rightarrow a = mP = (1) (4) = 4$ Paths

simplex $\rightarrow m = 1$

$R_{coil} = 10 \times 0.01 = 0.1 \Omega$, $R_{path} = 12 \times 0.1 = 1.2 \Omega$

$48 / 4 = 12$ coil/path

$$1/R_{eq} = \frac{1}{1.2} + \frac{1}{1.2} + \frac{1}{1.2} + \frac{1}{1.2} = \frac{4}{1.2}, \quad R_{eq} = \frac{1.2}{4} = 0.3 \Omega$$



Φ flux = W_b or V/δ

ω : Speed (rad/s), it need to be in rpm

$$n \text{ rpm} = \frac{720}{60} \omega \text{ (rad/s)}$$

$$E = K \Phi \omega$$

K : mechanical constant

$$K = \frac{ZP}{2\pi a}, \quad Z = ZCN, \quad P = \text{no. of poles}$$

E : induced voltage

$$V_T = E - I_A R_A$$

* التيار متغير فلازم اغير E_A على V_T ثابت
 * E_A متغير عن طريقين اما Φ او ω

V_T : Terminal voltage

Voltage Regulation, DC-generator

$$V_R = \frac{E_A - V_T}{V_T} \times 100\%$$



[P]: number of Poles [even]

[C]: number of coils

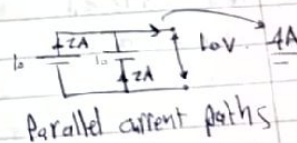
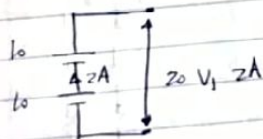
[N_c]: number of turns per coil

[Z]: number of conductors $Z = (2)(C)(N)$

[Single Layer Machine]: number of coils equal to half number of slots
coil per 2 slots

[Double layer machine]: number of coils equal to number of slots

Winding



Armature Winding of DC-Machine

Lap winding $q = mP$ q : number of paths
 P : number of poles
 m : $m=1$ simplex, $m=2$ duplex, $m=3$ triplex

Wave Winding $q = 2m$

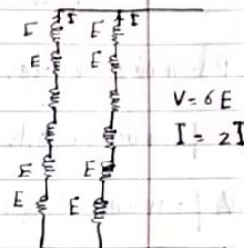
Ex: a DC machine have 24 slot, its a Single Layer, Simplex Lap Winding and it has 2 poles

Single Layer $\Rightarrow 12$ coil

simplex $m=1$

Lap winding $a = mp = (1)(2) = 2$ paths

Since we have 2 paths $12/2 = 6$ coil/path



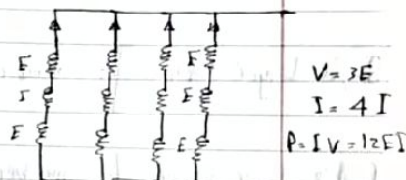
[b] if number of poles = 4, Same Lap winding, slot 24, single layer, simplex

- 12 coil

- $m=1$

- Lap $a = mp = (1)(4) = 4$ paths

$12/4 = 3$ coil/path



if $R_{coil} = 1 \Omega$, $R_{path} = R_{coil} + R_{coil} + R_{coil} = 3 \Omega$

$$\frac{1}{R_{eq}} = \frac{1}{3} + \frac{1}{3} + \frac{1}{3} + \frac{1}{3} = \frac{4}{3}$$

$$R_{eq} = \frac{3}{4}$$

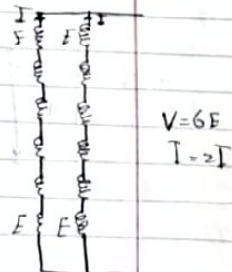
[c] if Single Layer Simplex Wave Winding, with 24 slot, 4 pole

Single $\Rightarrow 12$ coil

Simplex $\Rightarrow m=1$

wave $\Rightarrow a = 2m = 2(1) = 2$ paths

$12/2 = 6$ coil/path



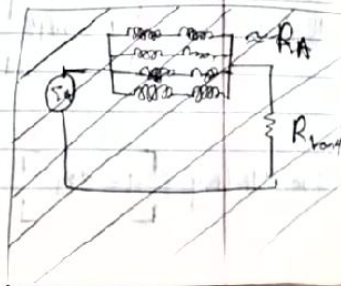
$$R_{eq} = \frac{R_{path}}{n \text{ path}}$$

Armature Resistance :

$$R_{coil} = N_c R_{turn}$$

$R_{conductor}$

$$[R_{turn} = 2 R_{conductor}]$$



Example: DC-generator, 4 poles, ~~100 A~~, $\phi = 0.02 \text{ Wb}$
 10 turn per coil, 120 slots, Single layer, $R_{\text{turn}} = 0.01 \Omega$, Simplex

- 1 - Determine Armature Resistance
- 2 - number of coils 4 - coil/paths
- 3 - number of paths

2 - Determine the induced voltage if the generator speed = 1200 rpm

3 - Determine the terminal voltage of the generator loaded by $R = 10 \Omega$

4 - Determine the Speed required for the generator to supply a load of 20 KW and $V_T = 500 \text{ V}$

5 - if the flux Induced by 50% determine the speed required for the generator to develop $E_A = 515 \text{ V}$

1. $R_{\text{turn}} = 0.01 \Omega$

$R_{\text{coil}} = (0.01) \times 10 = 0.1 \Omega$

$R_{\text{path}} = (0.1) \times 15 = 1.5 \Omega$

$R_A = \frac{1.5}{4} = 0.375 \Omega$

$R_A = 0.375 \Omega$

$R_{\text{eq}} = \frac{1.5}{4}$

10 turn per coil

$\frac{60}{4} = 15 \text{ coil/paths}$

2. $V_T = E - I_A R_A$, $E = K \phi \omega$

$E = \frac{PZ}{2\pi a} \phi \frac{1200}{60} \frac{2\pi}{60} = \frac{(4)(2 \times 10 \times 60)}{2\pi(4)} \times (0.02) \times \frac{1200 \times 2\pi}{60}$

$E = 480 \text{ V}$

Example: DC generator has 90 coils each coil with 4 turns
 Simplex Lap winding, $P = 4$ poles, if armature Resistance $R_A = 0.5 \Omega$
 Determine the following if the $\phi = 0.04 \text{ Wb}$

1- No Load Voltage if the generator Prime mover = 1000 rpm

2- Determine the Speed required the generator supplied at load of 4KW, $V_T = 500 \text{ V}$

- 90 coils - 4 turn/coil - 4 poles
- Simplex $m = 1$
- Lap $a = mp = (1)(4) = 4$ paths
- $R_A = 0.5 \Omega$
- $\phi = 0.04 \text{ Wb}$
- $Z = (4)(2)(90) = 720$



[a] - at no load $I_A = 0$, close to be zero so small to point that we can ignore it

$$V_T = E_A - I_A R_A$$

$$\phi = 0.04 \text{ Wb}$$

$$V_T = E_A = K \phi \omega, \quad K = \frac{ZP}{2\pi a} = \frac{(720)(4)}{2\pi(4)} = 114.591559$$

$$\omega = (1000) \frac{2\pi}{60} = 104.7197551 \text{ rad/s}$$

$$V_T = E_A = (0.04)(114.591559)(104.7197551) \approx 480 \text{ V}$$

$$[b] \quad V_T = E_A - I_A R_A$$

$$P_{\text{load}} = V_T I_A \quad I_A = \frac{4000}{500} = 8 \text{ A}$$

$$E_A = K \phi \omega$$

$$E_A = V_T + I_A R_A = 500 + (8)(0.5)$$

$$E_A = 504 \text{ V}$$

$$\omega = \frac{E_A}{K \phi} = \frac{504}{(0.04)(114.591559)}$$

$$\omega = \text{ans} \times \frac{60}{2\pi} = 1050 \text{ rpm}$$

المعادلة W في المجال $[rev/min] [rad/s]$

Example: A DC-generator which have Simplex Lap winding with 4 poles.
 $R_A = 0.25 \Omega$ number of coils = 80 $Z = 640$ conductor

- 1- Determine Induced voltage E_A if the generator loaded by 3KW 150V
- 2- Determine the Speed required for the generator to supply load in case (1) if the flux is 0.02 Wb
- 3- Determine Induced torque for case 1 and 2
- 4- Determine (T_{app}) if the friction losses amounts to 100W
- 5- if the induced voltage $E = 160V$ and $R_A = 5\Omega$ Determine T_{ind}

⑩ $P = 4$ poles $Z = 640$ conductor

Simplex $m = 1$

$$N = \frac{640}{(2)(80)} = 4 \text{ turns/coil}$$

Lap $a = mP = (1)(4) = 4$ paths

80 coil

$$\frac{80}{4} = 20 \text{ coil/path}$$

$$\text{⑪ } E_A = K \phi W \quad P_{out} = I_A V_T \quad I_A = \frac{3000}{150} = 20 \text{ A}$$

$$V_T = E_A - I_A R_A \quad E_A = 150 + (20)(0.25) = 155 \text{ V}$$

$$\text{⑫ } W = \frac{E}{\phi K} = \frac{155}{(0.02) \left(\frac{640 \times 4}{2\pi(4)} \right)} = \frac{60}{2\pi} = 726.5625 \text{ rev per minute}$$

$$\text{⑬ } T_{ind} = \frac{P_{mech}}{W} = \frac{E \cdot I_A}{W} = \frac{155 \times 20}{726.5625 \times \frac{2\pi}{60}} = 40.74 \text{ N.m}$$

$$\text{OR } T_{ind} = K \phi I_A = 40.74 \text{ N.m}$$

$$\text{⑭ } T_{app} = T_{ind} + \frac{P_{friction}}{W} = 40.74 + \frac{100}{726.5625 \times \frac{2\pi}{60}} = 42.054 \text{ N.m}$$

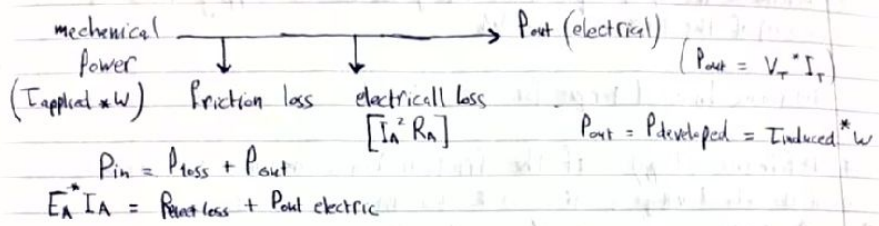
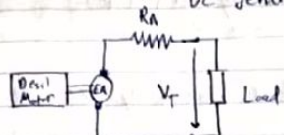
$\phi \propto I_a$
 $\phi \propto I_a$
 $\phi \propto I_a$
 $\phi \propto I_a$

10 10
11 11

Zero speed
→ 0

→ $[I_a]$ ϕ I_p I_m

DC-Generator [generate electricity]



$T_{\text{applied}} = T_{\text{input}}$ $\omega * T_{\text{input}} = P_{\text{input}}$ $T_{\text{input}} = \frac{P_{\text{input}}}{\omega}$ $T_{\text{induced}} = \frac{E_A * I_A}{\omega}$ $T_{\text{induced}} = \frac{K \phi \omega * I_A}{\omega}$	<p>in generation</p> $T_{\text{app}} > T_{\text{ind}}$ $P_{\text{app}} > P_{\text{ind}}$ $P_{\text{input}} > P_{\text{out}}$ $P_{\text{developed}} = T_{\text{induced}} * \omega$ $P_{\text{input}} = P_{\text{loss}} + P_{\text{output}}$	$T_{\text{induced}} = T_{\text{ind}}$ $\omega * T_{\text{output}} = P_{\text{output}}$ $T_{\text{induced}} = \frac{P_{\text{output}}}{\omega}$ $T_{\text{induced}} = \frac{V_T * I_A}{\omega}$
---	--	---

$T_{\text{induced}} = K \phi I_A$	$\omega T_{\text{imp}} = P_{\text{loss}} + P_{\text{output}}$ $T_{\text{input}} = \frac{P_{\text{loss}} + P_{\text{output}}}{\omega} = T_{\text{induced}}$
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a) 10
 b) 5
 c) 1

$$E_A = V_t + V_{int} = I_A R_L + I_A R_A = I_A (R_L + R_A)$$

$$I_A = \frac{E_A}{R_L + R_A} = \frac{160}{5 + 0.25} = 30.4 \text{ A}$$

$$\frac{T_1}{T_2} = \frac{I_{A1}}{I_{A2}} \text{ if } K\phi \text{ constant}$$

$$T_{ind} = \frac{P_{int}}{\omega} = \frac{E_A I_A}{\omega} = K\phi \omega I_A = K\phi I_A = (0.02) (30.4) \left(\frac{60}{2\pi} \right)$$

$$T_{ind} = 62.08 \text{ N.m}$$

$$T_1 = K\phi I_{A1}$$

$$T_2 = K\phi I_{A2}$$

$$\frac{20}{30.4} = \frac{40.74}{T_2}$$

$$T_2 = 61.9$$

DC-Generator with field circuit

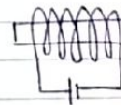
N.118

Permanent Magnet

electro Magnet

* Flux (ϕ) not controlled

$$\phi = \frac{MMF}{R} = \frac{NI}{R}$$



field circuit: where the flux produced in DC-Generator
 Armature circuit: where it deliver the current to the load

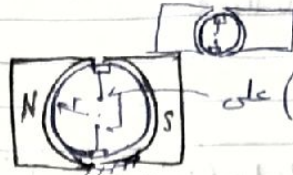
$$\phi \rightarrow I_f, [I_f \uparrow \Rightarrow \phi \uparrow, I_f \downarrow \Rightarrow \phi \downarrow]$$

$$e_{ind} = 2VBL$$

$$A_p = \frac{2\pi rL}{2}$$

area plane for one side
N or S

$$rL = \frac{A_p}{\pi}$$



المجال المغناطيسي (Magnetic field)

$$V = \omega r$$

velocity

$$e_{ind} = 2\omega r^* B^* L$$

$$V = 2\omega B r L$$

$$= 2\omega B^* \frac{A_p}{\pi}$$

$$e_{ind} = \frac{2^* \omega}{\pi}^* \phi \quad \left(K = \frac{2}{\pi} \text{ machine constant depend on the geometry of the machine} \right)$$

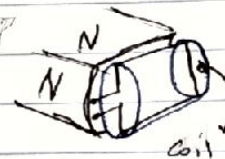
$$e_{ind} = K \phi \omega$$

$$K = \frac{ZP}{2\pi a}$$

C: number of used coils

Nc: turn per coil

$$Z = 2C N_c$$



coil

P: pol-number

a: number of current pole

$$e_{ind} = \frac{ZP}{2\pi a}^* \phi^* \omega$$

$$Z = 2^* 1^* 1 = 2$$

$$P = 2, a = 1$$

$$K = \frac{2^* 2}{2\pi^* 1} = \frac{2}{\pi}$$

المجال المغناطيسي (Magnetic field)
(coil 1)

$$e_{ind} = K \phi \omega$$



$$e_{in} = K^* \phi^* \frac{2\pi n}{60}$$

$$= \frac{ZP}{60a}^* \phi n$$

$$= \frac{ZP}{2\pi a} \times \phi \times \frac{2\pi n}{60}$$

$$e_{ind} = K' \phi n \quad \left[K' = \frac{ZP}{60a} \right]$$

Electric rotating machine [Generator]

N.117

* e_{ind} = generated voltage

(1 MV) ...

Gen Induced
Generator action

$$e_{ind} = (\vec{v} \times \vec{B}) \cdot \vec{L}$$

cross product

$$\vec{E} = v \cdot B \cdot \sin \alpha_{vB}$$

$$\alpha_{vB} = 90^\circ \rightarrow E = vB$$

$$E = \left[\frac{n}{s} \frac{v_s}{m^2} = \frac{v}{m} \right]$$

E: electric field

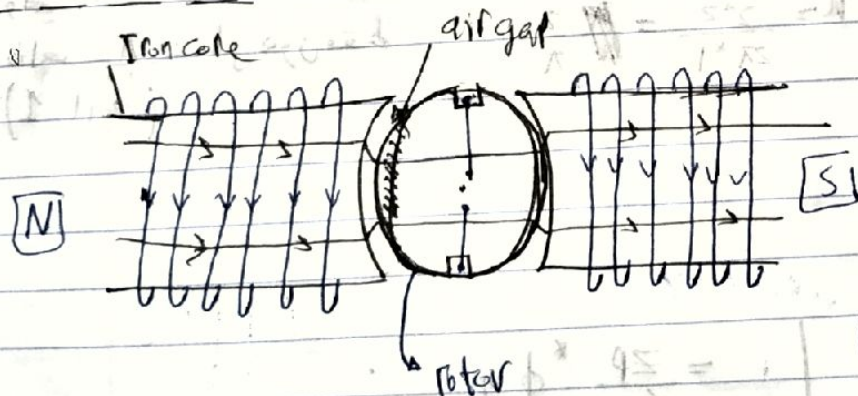
$$B \left[\frac{v_s}{m^2} = \text{Tesla} \right]$$

$$\vec{E} \cdot \vec{L} = E L \cos \alpha = EL = \frac{v}{m} \times n = v$$

$$v \left[\frac{m}{s} \right]$$

$$q_e = -1.6 \times 10^{-19} \text{ As}$$

$$\vec{F} = q \cdot \vec{E} \left[\text{As} \times \frac{v}{m} = \frac{W_s}{m} = N \right]$$



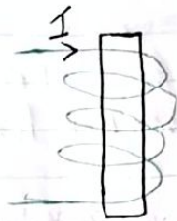
Reluctance
Reluctance Iron
Reluctance air

$$e_{ind} = z v B L$$

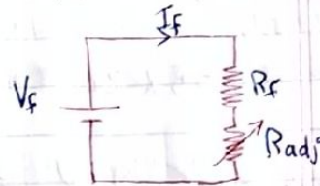
$$e_{ind} (ab): vBL \quad (bc) \neq 0 \quad (cd): vBL \quad (da) = 0 \quad \sum e_{indT} =$$

Shunt $\xrightarrow{\text{also}}$ Parallel

* $f \times$ { Permanent magnet \rightarrow un controlled
elector magnet \rightarrow controlled



* field circuit %



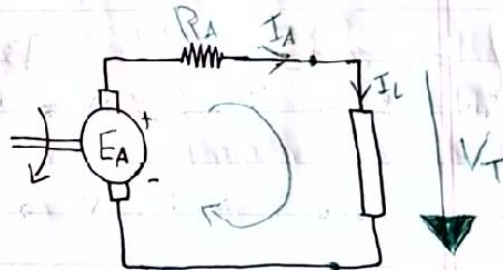
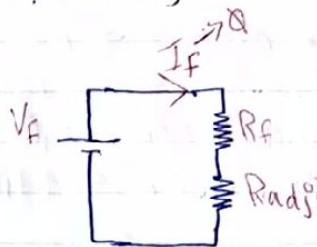
$$\Phi = \frac{MMF}{R} = \frac{NI}{R}$$

$$I_f = \frac{V_f}{R_f + R_{adj}}$$

(التي تمر في الملف)

* DC - generators types

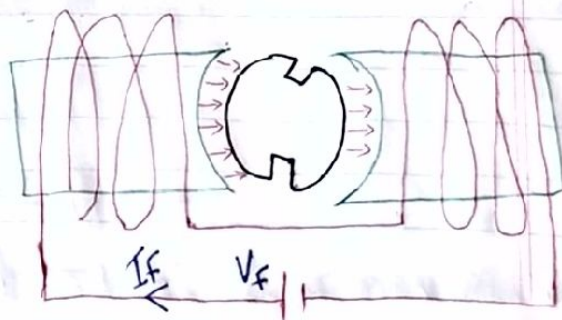
1) separately excited

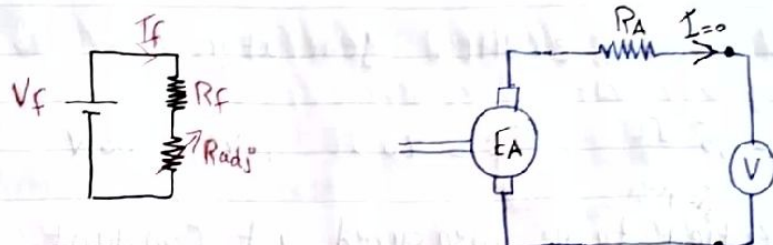


$$I_f = \frac{V_f}{R_f + R_{adj}}$$

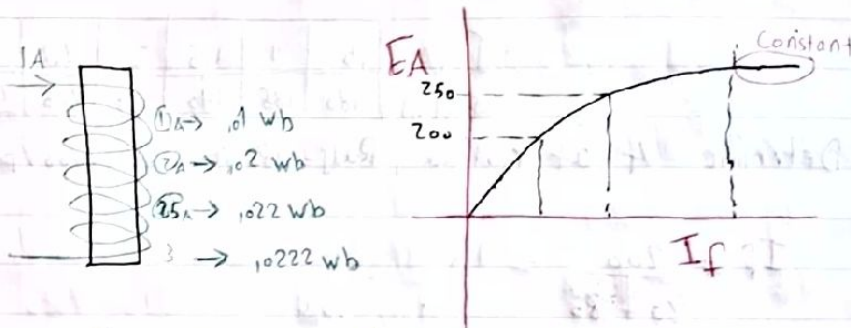
$$E_A = V_T + I_A R_A$$

$$I_L = I_A$$





$$E_A = K \Phi \omega$$



Ex: $E_{A1} = 100 \text{ V}$, $I_f = 1 \text{ A}$, $n = 1000 \text{ rpm}$

$E_{A2} = ??$, $I_f = 1 \text{ A}$, $n = 1500 \text{ rpm}$

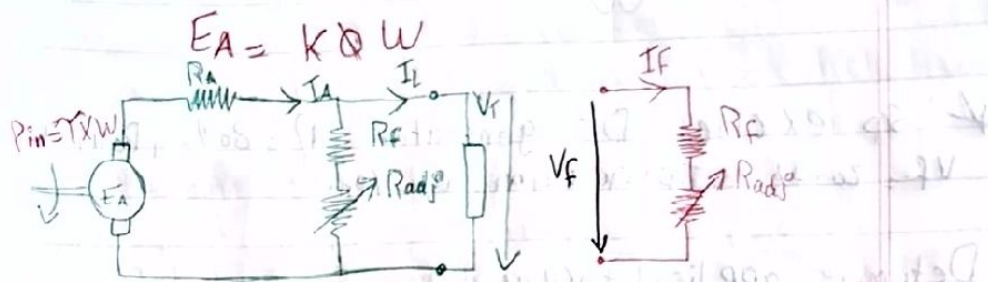
افضل اقسام 20% $E_{A1} = K \Phi \times n_1 \times \frac{2\pi}{60} = 100$

$E_{A2} = K \Phi \times n_2 \times \frac{2\pi}{60} = ??$

$$\frac{100}{E_{A2}} = \frac{n_1}{n_2} \Rightarrow E_{A2} = \frac{100 \times 1500}{1000} = 150 \text{ V}$$

E_A , R_{adj} , n يكون معطيا إما ثنين
منهم وينطق الثالث

* self excited DC - generator



Shunt generator

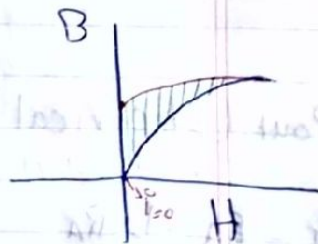
$$P_{dev} = E_A \times I_A = I_A^2 R_A + I_F^2 (R_F + R_{adj}) + P_{out}$$

$$V_T = E_A - I_A R_A$$

$$I_A = I_L + I_F$$

$$I_F = \frac{V_T}{R_F + R_{adj}}$$

Residual flux
بقايا فلو
بسم الله الرحمن الرحيم



$$H = \frac{NI}{l}$$



* Dc - shunt generator with $\eta = 80\%$
 $P_{in}(mech) = 5 \text{ kW}$, $V_T = 100 \text{ V}$, $R_f + R_{adj} = 100 \Omega$

$R_A = 0,5 \Omega$, speed = 1400 rpm

1) Determine developed power

$$P_{out} = 5000 \times 0,8 = 4000 \text{ Watt}$$

$$I_L = \frac{4000}{100} = 40 \text{ A}$$

$$I_f = \frac{V_T}{R_f + R_{adj}} = \frac{100}{100} = 1 \text{ A}$$

$$I_A = I_L + I_f = 40 + 1$$

$$P_{dev} = E_A \times I_A$$

$$E_A = 100 + 41 \times 0,5 = 120,5 \text{ V}$$

$$P_{dev} = 120,5 \times 41 = 4940,5$$

$$T_{ind} = \frac{P_{dev}}{\omega} = \frac{4940,5}{1400 \times \frac{2\pi}{60}} = 33,7 \text{ N.m}$$

$$T_{app} = \frac{5000}{1400 \times \frac{2\pi}{60}} = 34,1 \text{ N.m}$$

Ibrahim H Kojok

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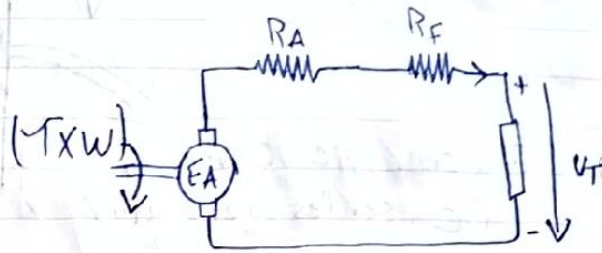


Like



Comment

2) series DC generator



$$V_T = E_A - I_A R_A \quad I_A = I_L = I_f$$

$$I_L \uparrow = I_A \uparrow = I_f \uparrow \Rightarrow E_A \uparrow \Rightarrow V_T \uparrow$$

$$-I_A (R_A + R_f) \uparrow \Rightarrow V_T \downarrow$$

E_A	I_A	V_T	
110 V	10 A	100 V	$(R_A + R_f) = 1 \Omega$
150 V	15 A	$150 - 15 \times 1 = 135 \text{ V}$	

50 turns

10 turns	E_A	I_A	V_T
	100 V	10 A	90 V
	105 V	15 A	$105 - 15 \times 1 = 90 \text{ V}$
	108 V	20 A	$108 - 20 \times 1 = 88 \text{ V}$

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Like



Comment

* Armature reaction % generator $\frac{AR}{N_f}$

If Armature reaction is not compensated is not neglected

$$I_f^* = I_f - \frac{AR}{N_f}$$

sep excited

$$I_f = \frac{V_f}{R_f + R_{adj}}$$

$$I_f^* = I_f - \frac{AR}{N_f}$$

shunt

$$I_f = \frac{V_T}{R_f + R_{adj}}$$

$$I_f^* = I_f - \frac{AR}{N_f}$$

series

$$I_f = I_A = I_L$$

$$I_f^* = I_f - \frac{AR}{N_f}$$

Compound

$$I_f^* = I_f \pm I_A \frac{N_s}{N_f} - \frac{AR}{N_f}$$

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Like



Comment



Like



Comment

* EX: Sep excited DC generator with magnetization table as follow

$R_A = 1.2 \Omega$, $R_f = 20 \Omega$, $N_f = 800$ turns, $V_f = 100$ V

I_f	1	2	2.3	2.5	2.7	2.9	3	4	1800 rpm
E_A	46	80	87	91	96	97	99	120	A
									V

1) Determine V_t at no load condition, $n = 1700$ rpm

$R_{adj} = 20 \Omega$

$V_t = E_A$ at no load

من حالة ال no load
ال I_f هي نفس I_f^*

$$I_f = \frac{100}{20 + 20} = 2.5 \text{ A}$$

9.1 $\rightarrow 1800$ rpm

?? $\rightarrow 1700$

$$E_A = 85.9$$

2) Determine voltage regulation if out put current = 20 A

$A_R = 100$ A turns, Speed = 2000 rpm, $R_{adj} = 20 \Omega$

* Full load (20) A

$$I_f = \frac{100}{20 + 20} = 2.5 \text{ A}$$

AR at
no load = 0



Like



Comment

$$I_f^* = 2,5 - \frac{100}{800} = 2,375 \text{ A}$$

$$\begin{matrix} 87 \leftarrow 1800 \\ I_A \leftarrow 2000 \end{matrix} \Rightarrow E_A = 96,6 \text{ V}$$

$$V_T = 96,6 - 20 \times 0,25 \Rightarrow 91,6 \text{ V}$$

$$V_T \text{ (no load)} \quad n = 2000 \text{ rpm}$$

$$I_f = \frac{100}{20+20} = 2,5$$

$$I_f^* = I_f - 0 = 2,5$$

$$91 \leftarrow 1800$$

$$I_A \leftarrow 2000 \Rightarrow E_A = 101,1 \text{ V} = V_T$$

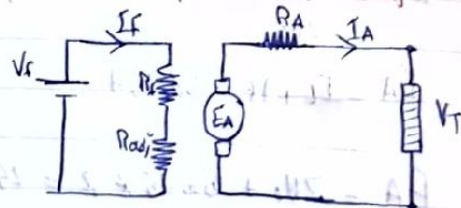
$$V_R = \frac{101,1 - 91,6}{91,6} \times 100\% = 10\%$$

- 3) If the generator has an armature reaction $A_R = 100 \text{ A.turns}$
 $I_{\text{load}} = 40 \text{ A}$, $n = 2000 \text{ rpm}$, $V_T = 100 \text{ V}$, Determine R_{ad}

$$E_A = 100 + 40 \times 0,25 = 110 \text{ V}$$

$$110 \rightarrow 2000 \text{ rpm}$$

$$E \rightarrow 1800 \Rightarrow E_A = 99 \text{ V}$$



$$\begin{array}{l} 218 \rightarrow 1700 \\ 251,39 \rightarrow n \end{array} \Rightarrow n = 1960,38 \text{ rpm}$$

* With AR $\Rightarrow 200$ A.turns

$$I_f^* = 1 - \frac{200}{1000} = 0,8 \text{ A}$$

$$\begin{array}{l} 215 \rightarrow 1700 \text{ rpm} \\ 251,38 \rightarrow n \end{array} \Rightarrow n = 1987,7 \text{ rpm}$$

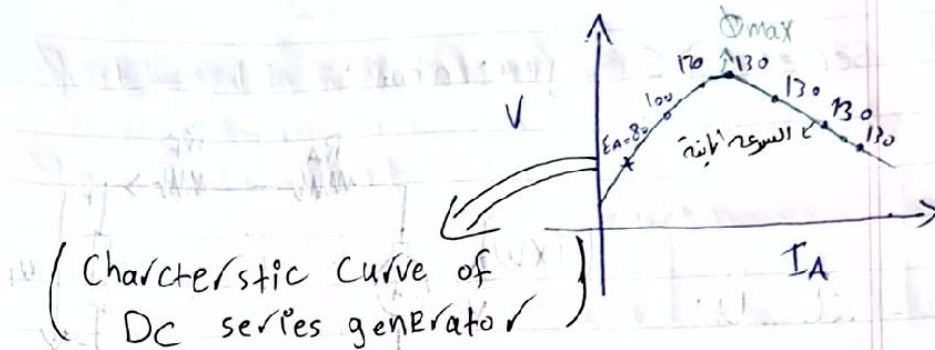
b) Determine rotational losses, applied torque induced torque for Gas(a)

Without AR :

$$\begin{aligned} \text{Rotation losses} &= P_{inP} - P_{out} - \text{elect losses} \\ &= P_{inP} - P_{dev} \\ &= 20 \times 746 - (251,39 \times 56,95) = 603,4 \text{ watt} \end{aligned}$$

$$T_{app} = \frac{P_{inP}}{\omega} = \frac{20 \times 746}{1960,38 \times \frac{2\pi}{60}} = 72,7 \text{ N.m}$$

$$T_{ind} = \frac{E_A \times I_A}{\omega} = \frac{251,39 \times 56,95}{1960,38 \times \frac{2\pi}{60}} = 69,7 \text{ N.m}$$



Ex: DC series generator $\eta = 90\%$, $P_{in} = 10 \text{ hp}$
 $V_T = 200 \text{ volt}$, $n = 1000 \text{ rpm}$

Determine developed power, T_{ind} , $T_{applied}$

$$P_{in} = 746 \times 10 \text{ watt}$$

$$P_{out} = 0.9 \times 746 \times 10$$

$$V_T = 200$$

$$I_L = \frac{0.9 \times 746 \times 10}{200} = I_F = I_A$$

$$E_A = 200 + I_A(1.6) \Rightarrow$$

$$1) P_{dev} = E_A \times I_A$$

$$2) T_{ind} = \frac{E_A \times I_A}{\omega} = \frac{E_A \times I_A}{1000 \times \frac{2\pi}{60}}$$

(4) friction losses $P_{in} - P_{dev}$

$$3) T_{app} = \frac{10 \times 746}{1000 \times \frac{2\pi}{60}}$$